Voyager

B U L L E T I N

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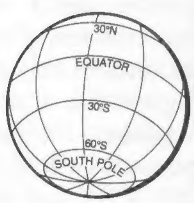
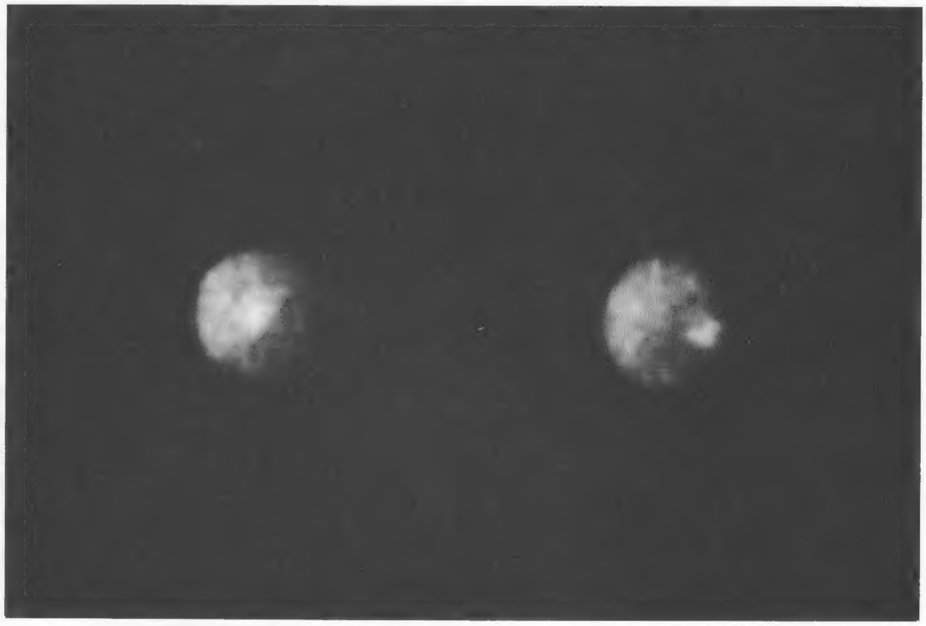
A bright cloud feature at about 30° south latitude can be seen moving across the face of Neptune in these images taken about two hours apart on January 23, 1989 by Voyager 2. (P-33983)





It's not just a fuzzy tennis ball after all . . .

A bright cloud feature on Neptune, similar to spots seen by planetary astronomers using Earth-based telescopes, is visible in images taken by Voyager 2 on January 23, 1989 when the spacecraft was about 309 million kilometers (185 million miles) from the planet. The fact that distinct cloud features are visible while the spacecraft is still so distant suggests that pictures taken as Voyager 2 approaches its August 1989 flyby of Neptune will show far more detail than was visible in the atmosphere of Uranus, which Voyager 2 encountered in January 1986. (Due to the lack of visible cloud features, Uranus has been lightheartedly described as a "fuzzy blue tennis ball," and less kindly as bland.)

The cloud is at about 30 degrees south latitude, and its motion during the time between images is consistent with the 17- to 18-hour rotation period derived from observations with Earth-based telescopes. The January images show details as small as about 6000 kilometers (3500 miles). The cloud has not yet been confirmed to be any of the cloud features seen on Neptune by Drs. Richard Terrile of JPL and Brad Smith of the University of Arizona at Las Campanas Observatory, Chile, in 1983, or by Dr. Heidi Hammel of JPL at the University of Hawaii's Mauna Kea facility in 1988. The features seen from these Earth-based telescopes were best seen through methane filters not available on Voyager 2, and imaging scientists had been somewhat concerned that such features might not be visible to Voyager 2's cameras.

The mottled appearance of Neptune in these frames is likely to be "noise" in the camera system. Color versions of these images, assembled from

pictures taken through violet, clear, and orange filters, show a dark band of clouds encircling the planet's southern pole (see map). The banded appearance is similar to cloud structures on the three other giant planets, Jupiter, Saturn, and Uranus. The natural color of Neptun is a pale blue-green, caused by the absorption of red light by methane gas in the planet's atmosphere.

Spacecraft Review and Status

Both Voyager spacecraft have survived in space for nearly twelve years, and although each has experienced some hardware failures, they are still in robust health and capable of returning valuable scientific data well into the next century.

Spacecraft Review

The core of each Voyager is a ten-sided bus, an aluminum framework ring which houses the spacecraft's electronics. The bus is about 45 centimeters (1-1/2 feet) high and 180 centimeters (about 6 feet) across.

Each spacecraft carries three computer subsystems: the computer command subsystem (CCS), the flight data subsystem (FDS), and the attitude and articulation control subsystem (AACS). Each computer has a backup, for a total of six computers, each with a separate memory.

The CCS is in overall control of the spacecraft. It monitors spacecraft activities, routes commands back and forth between the other computers, receives commands from Earth, and issues commands to send data back to Earth.

Computer programs (called sequence loads) to control the spacecraft are written on Earth and transmitted to the CCS. During cruise phases, a sequence load may operate the spacecraft for as long as six months; during a planetary encounter, a sequence load may operate the spacecraft for as few as 50 hours, depending on the complexity of the activities required to obtain the science data at the planet. A sequence load for a relatively quiet cruise phase may take about nine weeks to plan, build, and test before it is sent to the spacecraft, while an encounter load may take as long as 15 months.

Seven fault detection and correction routines are stored in the CCS at all times to automatically place the spacecraft in a safe state should the CCS detect a problem, such as an electrical short, a receiver or transmitter failure, or a failure in the CCS.

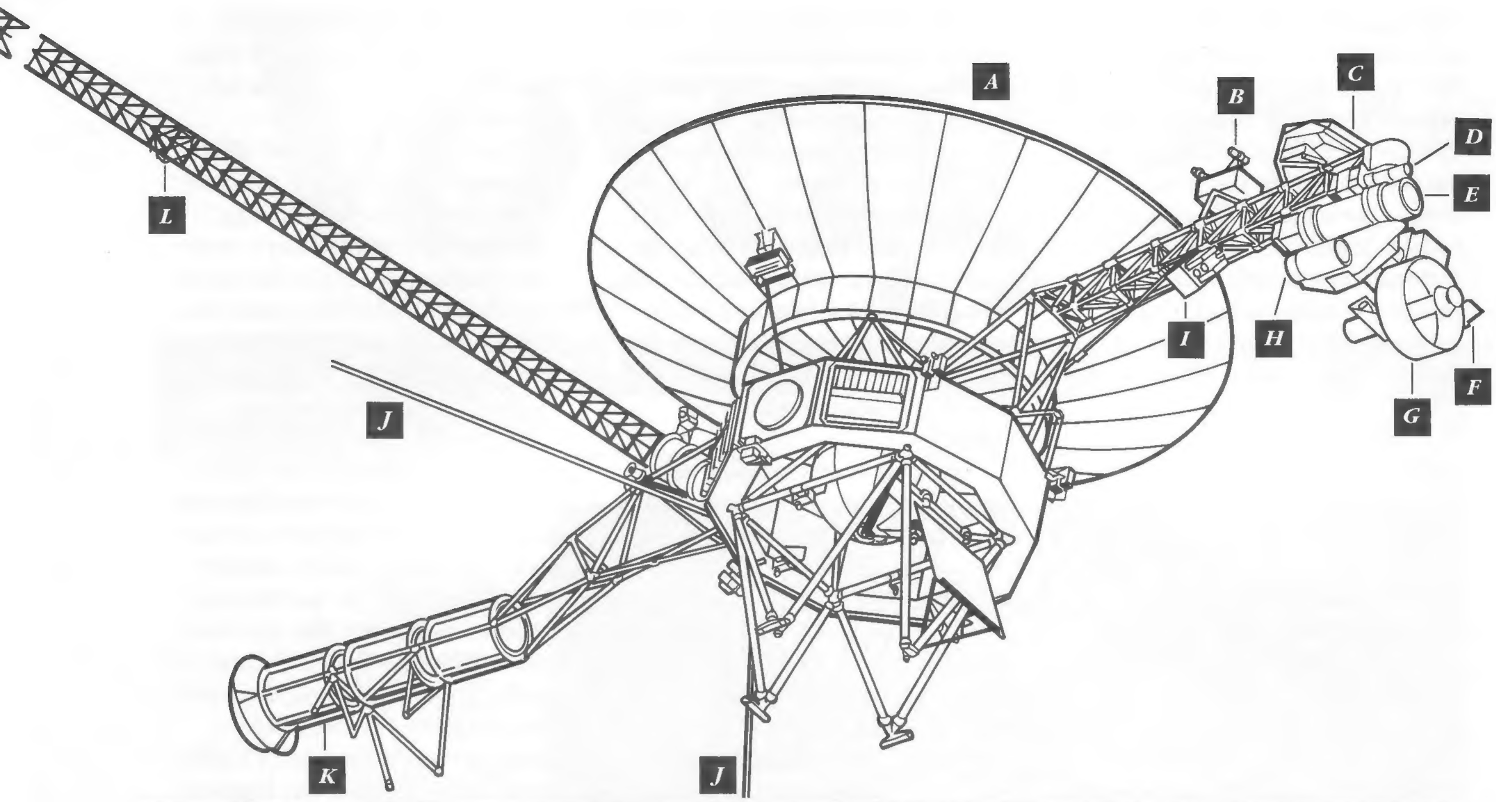
The FDS collects engineering and science data measurements and formats the data for transmission to Earth. The FDS controls the science instruments as directed by the CCS. The FDS also has several special data handling modes, such as data compression and encoding.

Data is often recorded on board the spacecraft on a high-capacity eight-track digital tape recorder for transmission to Earth at a later, more convenient time. For example, mission controllers may opt to wait until the spacecraft is "over" a specific DSN station before asking the spacecraft to transmit its data to Earth. Similarly, data is recorded during high-activity periods, or when the spacecraft is behind a planet.

The AACS maintains the pointing of the spacecraft's antenna, orients or maneuvers the spacecraft, and points (articulates) the scan platform. The spacecraft is stabilized on three axes (pitch, yaw, and roll) and senses its orientation either through its internal gyroscopes, or by tracking two celestial bodies (typically the Sun and a reference star such as Canopus). The AACS maintains the spacecraft's orientation by using small rocket thrusters which expel hydrazine propellant, a compound of nitrogen and hydrogen. At launch, each spacecraft carried about 105 kilograms (232 pounds) of hydrazine. During its 11-1/2 years in space, Voyager 2 has used about 60 kilograms (140 pounds) of hydrazine.

The Voyagers communicate with Earth via their telecommunications systems, which include a 3.65-meter (12-foot) diameter high-gain antenna, a low-gain antenna, an S-band receiver, and X- and S-band transmitters. The spacecraft can receive only in the S-band frequencies, at about 2100 megahertz (MHz). They can transmit both at S-band (about 2300 MHz) and at X-band (about 8400 MHz). (By comparison, typical FM radio transmission is at about 100 MHz, while AM radio transmissions range from about 50 to 160 kilohertz). The X-band frequency has a narrower beamwidth and thus a tighter focus than does the S-band. The wavelength of the X-band signal is 3.5 centimeters (less than 1.5 inches), while the wavelength of the S-band signal is slightly longer at 13 centimeters (about 5 inches).

Each Voyager is powered by three radioisotope thermoelectric generators (RTGs), which produce electrical energy through the conversion of heat generated by the radioactive decay of plutonium-238. At launch, the power output of the



A	*High-Gain Antenna*	E	*Imaging, Narrow-Angle*	I	*Low-Energy Charged Particles Detector*
B	*Cosmic Ray Detector*	F	*Ultraviolet Spectrometer*	J	*Planetary Radio Astronomy and Plasma Wave Antennas (2)*
C	*Plasma Detector*	G	*Infrared Spectrometer and Radiometer*	K	*Radioisotope Thermoelectric Generators (3)*
D	*Imaging, Wide-Angle*	H	*Photopolarimeter*	L	*Magnetometer (1 of 4)*

RTGs was about 423 watts. The power output steadily declines as the plutonium decays, and is now about 380 watts. The science instruments require about 105 watts, or about the same wattage as a typical light bulb.

Instruments Description and Health

Each spacecraft carries instruments for ten scientific investigations. Optical instruments for four of the investigations are mounted on a movable (scan) platform at the end of a short boom. Instruments for six more investigations measure magnetic and electrical fields and charged or neutral particles in space and in the vicinity of planets. In addition, the spacecraft's radio is used for an eleventh investigation.

Scan Platform Instruments

Imaging Cameras (ISS): Each Voyager spacecraft carries two imaging cameras: a 200-mm, f/3.5 wide-angle camera using a refracting telescope and a 1500-mm f/8.5 narrow-angle (telephoto) camera using a reflecting telescope. Each camera uses a one-inch selenium-sulfur vidicon to convert an optical scene into electrical signals. Each frame consists of 640,000 picture elements (pixels), each of which is expressed as a level of grey on a scale from 0 (black) to 255 (white). Color scenes are reconstructed on Earth by electronically combining images taken through different filters. The sensitivity of the filters ranges from 3460 (ultraviolet) to 6184 angstroms (red-orange). (The human eye can see in the range from 3800 to 6800 angstroms.)

Voyager 2's narrow-angle camera has dust specks on the vidicon which result in faint, doughnut-shaped blemishes in images. In addition, the emission of the vidicon cathode in the narrow-angle camera has decreased since launch.

Imaging team leader is Dr. Bradford A. Smith of the University of Arizona, Tucson, Arizona; deputy team leader is Dr. Larry A. Soderblom of the U.S. Geological Survey, Flagstaff, Arizona.

Photopolarimeter (PPS): The photopolarimeter measures the way light is scattered from particles in an atmosphere or on a surface. By studying the polarization of reflected light as the lighting geometry changes during a flyby, scientists can make inferences about the nature of a planetary surface or atmosphere. The photopolarimeter can also be used to study rings by measuring the intensity of a background star as the starlight passes through the rings.

The photopolarimeter consists of a 200-mm Cassegrain telescope with filters, polarization analyzers, and a photomultiplier tube to convert incoming light into electronic signals. It covers three wavelengths in the region between 265 and 750 millimicrons. Five of the eight original filters and four of the eight original analyzers are no longer accessible.

Principal investigator is Dr. Lonne Lane of the Jet Propulsion Laboratory, Pasadena, California.

Infrared interferometer spectrometer and radiometer (IRIS): IRIS measures the temperatures of planets and satellites to determine their energy balance (the balance between the heat received from the Sun and the heat—if any—generated by the body itself). Global temperature maps are produced for each body. IRIS also studies the molecular composition of atmospheres, and can detect molecules such as hydrogen, ammonia, methane, ethane, acetylene, and other complex hydrocarbons. IRIS uses a 50-cm telescope to gather light and direct it into the optics. The radiometer measures the solar radiation reflected from a body in the range from 0.3 to 2.0 microns, while the interferometer measures radiation emitted in the middle- and far-infrared (4.0 to 55 microns). The neon reference signal has decreased, and the interferometer has lost some of its sensitivity due to degraded alignment of its optical components.

Principal investigator is Dr. Barney J. Conrath of NASA's Goddard Space Flight Center in Greenbelt, Maryland.

Ultraviolet spectrometer (UVS): The ultraviolet spectrometer studies the chemical composition, temperature, and structure of atmospheres by observing how ultraviolet light from the Sun is absorbed or scattered after it enters the atmosphere of a planet or satellite. It also studies ultraviolet light coming from stars.

The UVS detects and measures ultraviolet radiation in the range from 500 to 1700 angstroms. Included in this range are the atomic hydrogen Lyman alpha series, molecular hydrogen, helium, methane (natural gas), acetylene, ethane, and other atmospheric hydrocarbons.

Principal investigator is Dr. A. Lyle Broadfoot of the University of Arizona, Tucson, Arizona.

Radio Science

Effects on Voyager's radio signals can help determine the structure and composition of an atmosphere, the size and distribution of particles in rings, and the characteristics of planetary

and satellite gravitational fields.

Team leader is Dr. Len Tyler of Stanford University's Center for Radar Astronomy, Stanford, California.

Fields & Particles Instruments

Magnetometers (MAG): Each Voyager carries four magnetometers mounted along a 13-meter (43-foot) boom. The magnetometers help characterize planetary magnetic fields, as well as the structure of a magnetosphere and its interactions with planetary moons. Interplanetary magnetic fields are also measured.

The dynamic range of the low-field magnetometers is from about 0 to 50,000 gammas, while the range of the high-field magnetometers is from about 1/2 to 20 gauss (50,000 to 2 million gammas).

Principal investigator is Dr. Norman F. Ness of the University of Delaware's Bartol Research Institute, Newark, Delaware.

Plasma (PLS): Plasmas are hot ionized gases that flow like liquids and are affected by magnetic fields. Plasmas are often trapped by planetary magnetic fields and interact with planetary satellites and rings. The plasma detector characterizes these interactions and also determines the properties and radial evolution of the solar wind. PWS measures protons and electrons in the energy range from 10 to 5950 volts and ions from 20 to 11,900 volts.

Principal investigator is Dr. John W. Belcher of the Massachusetts Institute of Technology's Center for Space Research, Cambridge, Massachusetts.

Low-Energy Charged Particles (LECP): The LECP instrument measures the composition and energy spectrum of low-energy charged particles trapped in planetary magnetospheres, as well as the distribution and variation of galactic cosmic rays. The instrument measures electrons in the range from about 15,000 volts (15 keV) to more than 11 MeV, and protons and heavier ions in the range from 20 keV to 150 MeV, as well as nuclei in the range from about 47 keV to more than 200 MeV per nucleon. The sensitivity of the LECP has decreased slightly over the years.

Principal investigator is Dr. S. M. (Tom) Krimigis of the Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland.

Cosmic Rays (CRS): Cosmic rays are the most energetic particles found in nature and are atomic nuclei (primarily protons) and electrons. Voyager's cosmic ray package uses seven telescopes to analyze cosmic-ray nuclei ranging from hydrogen through iron, over an energy range from about 1 to 500 MeV. Principal investigator is Dr. Edward C. Stone of the California Institute of Technology, Pasadena, California.

Planetary Radio Astronomy (PRA): Radio emissions from planets are generated by charged particles spiraling along magnetic field lines. Since the magnetic field originates in the interior of a planet, the radio emissions are a good indication of processes within the planet. Radio emissions from the Sun and

from lightning in a planet's atmosphere can also be detected. The planetary radio astronomy experiment uses two 10-meter (33-foot) whip antennas to listen for planetary radio emissions over a range from 1.2 kHz to 40.5 MHz. The PRA has occasional, seemingly random power problems which the spacecraft is now programmed to sense and automatically correct.

Principal investigator is Dr. James W. Warwick of Radiophysics, Inc., Boulder, Colorado.

Plasma Waves (PWS): Plasma waves are low-frequency oscillations in the plasmas in interplanetary space and in planetary magnetospheres. The plasma wave instrument detects and measures plasma wave interactions in planetary magnetospheres and detects interactions between a planetary magnetosphere and the solar wind. It can detect particles in the ring plane and measure their impact rate on the spacecraft. The PWS shares the two whip antennas with the PRA investigation to provide the equivalent of a single 7-meter antenna. PWS covers the frequency range from 10 Hz to 56.2 kHz.

Principal investigator is Dr. Donald Gurnett of the University of Iowa, Iowa City, Iowa.

Voyager 2's Health

Both Voyagers have experienced several health problems since launch, some minor and some rather major ones. Nonetheless, mission controllers have in every case been able to identify the problems and provide a way to continue to meet mission objectives.

In September 1977, about a month after launch, Voyager 2 suffered a hardware failure in the FDS. As a result, 15 engineering measurements can no longer be made (about 215 engineering measurements remain).

In 1978, eight months after launch, Voyager 2's main radio receiver failed, and a tracking loop capacitor failed in the backup receiver. As a result, Voyager 2 can receive signals in only a narrow "window" of frequencies—and the window slides. The window is about 1000 times narrower than it originally was, and temperature changes in the radio receiver of even 1/4° cause the window to slide up or down in frequency. Temperature changes can be caused by heat generated by the spacecraft's electronics. The flight team has devised a rigorous routine for commanding the spacecraft. Signals are sent several times at different frequencies to determine the receiver's current frequency "window". Commands are then transmitted, after calculating where the receiver's "window" will be, and taking into account how the signal frequency will change due to the Earth's rotation and other motions.

The receiver problem occurred nearly a year before Voyager 2 reached its first objective, the Jupiter system, yet successful encounters of Jupiter, Saturn, and Uranus followed.

In August 1981, just after Voyager 2 passed Saturn, the scan platform quit moving. Three years of intensive analysis and testing of similar parts on Earth, and of the scan platform on Voyager 1, led to a failure model and to guidelines for safe usage of the platform. The failure has been attributed to a lack of full lubrication of the bearing area between the gear and pin in the azimuth actuator. Lubricant has probably migrated back to the bearing surfaces, healing the problem. Adherence to the guidelines for safe usage permitted Voyager to complete a successful encounter with Uranus in 1986, returning some of the highest resolution images ever taken of solar system bodies. The scan platform was programmed to track the target body during certain exposures.

The Uranus encounter was not without its surprises, either. Just days before its closest approach to Uranus, Voyager 2 suffered the loss of one word of memory in one FDS processor. As a result, bright and dark streaks appeared in images. Only imaging data was affected, and a software patch was sent to bypass the failed bit.

Despite a little arthritis, a little hearing problem, and some loss of memory, Voyager 2 is still in excellent operating condition, and gaining rapidly on Neptune and Triton.

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